BIODIESEL FROM YELLOW MUSTARD OIL

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University of Idaho

Charles L. Peterson, Ph.D

Joseph Thompson, BAE Technician

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16. Abstract

The goals of this project were to evaluate locally developed yellow mustard cultivars, experiment with the biodiesel made from them through stationary engine and on-road testing and to sponsor and host the tenth biennial bioenergy conference.A 2001 Volkswagen 1.9 L TDI beetle and a 1999 Cummins powered Dodge diesel pickup truck continue to run on 100 percent yellow mustard biodiesel (MEE). The beetle has accumulated a total of 12,210 miles, and the Dodge, 27,230 miles. No operational problems have been noted. Oil analysis results have all been normal. The Vandal Trolley has been has been running on B20 to document the long-term effects of biodiesel on stop-and-start drives.Stationary engine tests include the completion of a 200-hour EMA durability test with a 24 hp, 3 cylinder, Yanmar DI engine running on MEE. During the durability test MEE power averaged 6.0 percent lower; fuel consumption was 2.2 percent higher and BSFC (hp-hrs/gal) was 8 percent higher than when operated on diesel.The Tenth Biennial Bioenergy Conference, Bioenergy 2002, "Bioenergy for the Environment," was held in Boise Idaho, at the Center on the Grove, the downtown conference center, from Sept. 22 – 26, 2002.

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EXECUTIVE SUMMARY

The goals of this project were to continue with the evaluation of locally developed yellow mustard cultivars, experiment with the biodiesel made from them through stationary engine and on-road testing as well as steady state emissions tests and to sponsor and host the tenth biennial bioenergy conference.

Based on the recommendations of Dr. Jack Brown, plant breeder and researcher with UI Plant, Soils and Etymological Sciences Department, two mustard varieties, Ida Gold and Pacific Gold, were selected. Variety trials showed that these two cultivars were well suited for the Northwest and produced high value meal to be used for soil fumigation. Oil extraction and biodiesel production efficiencies have been somewhat less for the yellow mustards (due to lower initial oil content) than for rapeseed and canola. Extraction averaged 58 and 70 percent compared to 78 to 80 percent for rapeseed and canola. Biodiesel production had a yield of 3 percent less than when rapeseed and/or canola were used.

The 2001 Volkswagen 1.9 L TDI beetle continues to run on 100 percent yellow mustard biodiesel (MEE). It has accumulated a total of 12,210 miles. This vehicle has been used to demonstrate the feasibility of using biodiesel in smaller vehicles and for urban use. The "Idaho Mustard Bug" has been used in numerous demonstrations, schools, field days, open houses, and has been particularly effective in teaching K-12 students about the advantages of alternative fuels. It was displayed at the Renewable Energy Fair in Sun Valley, the Ethanol Conference at West Yellowstone and the Bioenergy 2002 Conference in Boise.

A 1999 Cummins powered Dodge diesel pickup truck was also used for on-road and dynamometer testing. The truck has operated on MEE for 27,230 miles and has averaged 15.78 mpg. No operational problems have been noted. Oil analysis results from samples of the engine oil were normal.

The Vandal Trolley, which is powered by a Cummins 5.9 liter diesel has been has been running on B20 (20 percent biodiesel) and is a demonstration project to document the efficiency and long-term effects of this alternative fuel on stop-and-start drives.

Stationary engine tests include the completion of a 200-hour EMA durability test with a 24 hp, 3 cylinder, Yanmar DI engine running on MEE. During the durability test MEE power averaged 6.0 percent lower; fuel consumption was 2.2 percent higher and BSFC (hp-hrs/gal) was 8 percent higher than when operated on diesel.

In August and September of 2001, a series of chassis dynamometer emissions tests were run with a 1994 Dodge Cummins diesel powered pickup. A 602 SuperFlow Dynamometer was used to correlate emissions readings from a portable 5-gas analyzer with emissions readings obtained at the Los Angeles Mass Transit Authority testing facility with the same truck in 1997. Results of these tests showed that only the nitrous oxide data was comparable.

The Tenth Biennial Bioenergy Conference, Bioenergy 2002, “Bioenergy for the Environment,” was held in Boise Idaho, at the Center on the Grove, the downtown conference center, from Sept. 22–26, 2002. The conference highlighted the latest in biomass energy technology form around the world. Over 200 presenters, both oral and posters, were delivered and over 500 participants registered.

DESCRIPTION OF PROBLEM

Biodiesel has been under study at the University of Idaho since 1979. The program is recognized as a pioneering research program with feedstocks from rapeseed oil and used French fry oil (Chase et al, 2000). It is also recognized for the use of ethanol as the alcohol for the esterification reaction. While most biodiesel is produced with methanol, most of the biodiesel produced here is from ethanol. The ethanol comes from used potato wastes at the J. R. Simplot plant in Caldwell, Idaho. The fuel produced has been used in a variety of off-road and on-road engine tests and research projects.

Biodiesel produced from vegetable oil or animal fat can be used as a replacement for petroleum fuel in diesel powered vehicles such as trucks, tractors, and other heavy equipment including many marine applications. Most biodiesel is produced by esterifying the lipids to produce esters. This process reduces the viscosity and removes the glycerol making the resulting fuel more compatible with the engine. Most biodiesel is made from vegetable oil such as soybean, canola, rapeseed, sunflower or mustard and an alcohol.

The biodiesel process is a chemical reaction involving alcohol, such as methanol or ethanol into which is added a catalyst such as sodium hydroxide or potassium hydroxide. This mixture is stirred into the vegetable oil causing a chemical reaction, which separates the vegetable oil into two components: ester and glycerol. The ester is lighter than the glycerol and so rises to the top after the reaction is complete. The ester, after carefully washing to remove all remaining catalyst, alcohol and glycerol, is the product used as a fuel in diesel engines. The second component is a heavier liquid called glycerol. Glycerol has many food and industrial uses such as cosmetics, toothpaste, pharmaceuticals, foodstuffs, plastics, explosives, and cellulose processing to name a few. However, the material obtained from biodiesel production requires purification before it could be used for these purposes.

The UI produced biodiesel has emphasized use of feedstocks of economic significance to the state. Rapeseed, canola and yellow mustard are good alternative crops in northern Idaho. University of Idaho plant scientists developed yellow mustard varieties, which have the potential to significantly reduce the cost of the oil used in biodiesel production. This project is for purposes of producing quantities of biodiesel from these locally grown varieties to test in both laboratory engines and in several on-road vehicles. As part of the test protocol, fuel characterization tests will be conducted to verify that the biodiesel produced meets the interim ASTM standard for biodiesel.

APPROACH AND METHODOLOGY

Objectives:

The objectives of the project were to

1. Continue to produce and test biodiesel from locally developed strains of yellow mustard oil, specifically Ida Gold and Pacific Gold.
2. Demonstrate the on-road use of yellow mustard oil as a feedstock for biodiesel.
3. Cooperate with Auxiliary and Parking Services by producing mustard oil biodiesel for the recently acquired "Vandal Trolley" which is used for transporting students, faculty and alumni on and off campus for special events.
4. Continue emissions testing with a chassis dynamometer to determine if a correlation can be developed between test data from local mode tests using a five gas analyzer and test data from the LA MTA emissions tests conducted earlier.
5. Complete EMA test on a 27 hp Yanmar engine with Ida Gold yellow mustard biodiesel.
6. Co-sponsor the Tenth Biennial bioenergy conference, Bioenergy 2002.

Facilities:

The Department of Biological and Agricultural Engineering has facilities for producing, characterizing, and testing alternative fuels. Laboratory facilities include a biodiesel production pilot plant facility; an analytical laboratory; an EMA computer controlled durability engine test facility; a machine vision system for evaluating injector coking; a maintenance and engine diagnostics laboratory for vehicle and engine research, and a double roll chassis dynamometer facility.

The biodiesel production pilot plant consists of two CeCoCo seed presses of 45 kg/hr, each with seed pre-heating capability and instrumented feed bins; several small biodiesel reactors; two batch type reactors, one with 1000 liter capacity and the second of 2000 liter capacity. Fuel storage tank availability includes a variety of 1050-liter totes and several 2000-liter tanks. It is an approved BATF small fuel production plant and can obtain non-denatured alcohol and store it in an approved on-site locked area.

The analytical laboratory is equipped for biodiesel research. Fuel characterization data which can be performed at the UI include: heat of combustion, cloud point, pour point, viscosity, density, flash point, acid number, fatty acid, free and total glycerol determination, water and sediment, and cold filter plugging point. Additional fuel characterization including cetane number, ash, particulate matter, copper corrosion, elemental analysis, iodine number, and boiling point are performed by Magellan Analytical Services, Kansas City, KS. These parameters provide the information required for the ASTM standard D 6751 for biodiesel.

A SuperFlow SF-602 chassis dynamometer is available for in-chassis engine performance analysis and diagnosis. The SF-602 is a double drum, water brake dynamometer capable of about 750 hp in single drum configuration. Measurements taken by the dynamometer include vehicle torque, vehicle speed, engine speed, engine coolant temperature, air intake temperature, exhaust temperature, engine oil pressure, manifold pressure and volumetric fuel consumption.

An EMS Model 5001 emissions five-gas analyzer capable of reading HC, O_2, CO, CO_2, and NOx was used to perform the emissions tests. Readings are generally reported as parts per million or percentage of exhaust gases.

Departmental owned research vehicles purchased exclusively for biodiesel research include a 76 kW John Deere 3150 four wheel drive tractor, a 1994 Cummins 5.9B powered Dodge pickup truck; a 1999 Cummins 5.9B electronically injected Dodge four wheel drive pickup truck; and a 2001 Volkswagen 1.9 L diesel powered new beetle. The latter two vehicles are used exclusively for testing on 100 percent yellow mustard biodiesel fuel.

Data Collected:

1. Oil extraction and biodiesel production data.
2. On-Road Tests
3. Engine Performance Tests including vehicle chassis dynamometer tests and stationary engine torque test.
4. EMA durability test.
5. Chassis dynamometer steady state emissions tests with the five-gas analyzer.

Procedure for Emissions Tests:

The vehicle tested was a 1994 Dodge pickup with a DI, turbocharged and intercooled, 5.9-L Cummins diesel engine. The vehicle had accumulated 1500 miles on diesel and 109,270 miles on rape ethyl ester at the time of this test.

Biodiesel from rapeseed oil was made to compare its emissions with that of diesel. The engine was not modified in any way for use with the vegetable oil fuels. The fuel delivery system was modified for convenience of changing fuels between test runs. Fuel delivery and fuel return lines were broken and an electrically operated tank switching valve was installed so that stub lines with quick couplers could be installed on one side of the valve while the main fuel tank was attached to the other. The fuels were held in five-gallon cans with supply lines attached near the bottom and return lines near the top. The lines had quick couplers to mate with the stub lines on the truck. The fuel filter on the truck was changed after each test. Upon startup with the new fuel the return line was diverted to flush any residual fuel from the system.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Yellow Mustard Processing:

Two new varieties of mustard seed (Ida Gold and Pacific Gold) were developed by the UI Plant Science Department. They show great promise as a lower cost feedstock for biodiesel with valuable seed meal that can be used as a soil fumigant. In synergistic cooperation with PSES, BAE personnel processed mustard seed to provide meal for fumigation research while the oil was used to make biodiesel for further engine and on-road testing.

During the time period of this project, the BAE oilseed processing plant was used to process approximately eight tons of Ida Gold and four tons of Pacific Gold. The Ida Gold seed had an average oil content of 23.7 percent and yielded 392 gallons of oil for biodiesel production and 13,028 pounds of meal for soil fumigation research. The Pacific Gold seed had a higher oil content of 37 percent and yielded 285 gallons of oil and 5,840 pounds of meal. The meal from both varieties of seed had an oil content of approximately 10 percent. Oil extraction has been less efficient from yellow mustard than is normally experienced with rapeseed and canola due to the lower oil content of the seed. Ida Gold has only about 24-27 percent oil content and Pacific Gold has about 34-38 percent compared to 40-45 percent for rapeseed and canola. Extraction efficiency, with the small screw presses, for Ida Gold and Pacific Gold was 58 and 70 percent respectively compared to 78-80 percent for rapeseed and canola.

The biodiesel produced from the mustard oils was used to: complete a 200 hour EMA test with a 1.2 L Yanmar engine; perform emissions tests: fuel two Dodge trucks, a Volkswagen Beetle, a Trolley, two tractors, a swather and a combine.

On-Road Demonstration of Yellow Mustard Biodiesel

The test vehicles are a 2001 VW Beetle, with a 1.9 liter, direct injection, 4 cylinder engine, a 1999 Dodge truck with a Cummins direct injection, 5.9 L electronically fuel injected engine and a 1994 Trolley with a 5.9 L Cummins. The 1999 Dodge has logged 27,230 miles, the 2001 VW Beetle has logged 12,210 miles and the Trolley has been operating on B20 for about a year now. Other vehicles at the University farm operating on B50 include a John

Deere 3150, a Winterstiger plot combine, a Swift plot swather and a 34 hp Mitsubishi Bison. There have been no fuel related problems associated with the operation of these vehicles except for a shorter than normal fuel filter change interval noted on the Dodge. Fuel filters have been changed at about 8,000 mile intervals.

FIGURE 1. The 2001 VW Beetle—Mustard Bug

The average oil change interval for the Dodge has been 3,890 miles. Oil samples were taken and analyzed for wear metals, soot and viscosity. All data to date, following the initial break-in period, has been well within the normal range.

Table 1. Engine oil analysis wear metals for 1999 Dodge.

Miles	Iron	Lead	Copper	Aluminum	Silicon
3020	64	5	24	3	22
7535	55	4	12	2	22
11569	34	1	5	2	15
14743	37	2	3	2	10
18775	17	3	2	2	5
23105	19	2	1	2	5
27230	22	2	1	1	5

FIGURE 2: The Vandal Trolley

The Vandal Trolley was the idea of a team of UI business and engineering student interns working with UI's Division of Finance and Administration. The student team's research showed a need for shuttling persons with disabilities, campus users navigating the hills and carrying cumbersome class projects, visitors unfamiliar with campus and other such clientele. UI's Auxiliary and Parking Services subsequently purchased the bus from the City of Kellogg with a grant from the state of Idaho.

The Trolley, powered by a Cummins 5.9 liter diesel coupled to a three speed automatic transmission, serves as a demonstration project documenting the efficiency and long-term effects of alternative fuel on stop-and-start drives. During the time of this study, the demonstration was just getting under way having had its debut on the 2001 Vandal Friday.

Emissions Testing

In August and September of 2001 a series of chassis dynamometer emissions tests were run with a 1994 Dodge Cummins diesel powered pickup. A 602 SuperFlow Dynamometer was used to correlate emissions readings from a portable 5-gas analyzer with emissions readings obtained at the Los Angeles Mass Transit Authority testing facility with the same truck in 1997 (Peterson et al., 2000). The analyzer was an EMS Model 5001 and was capable of measuring NO_X and HC in ppm, and O_2, CO_2, and CO as a percentage of exhaust gases. The fuels used for these tests were REE and Phillips 66 standardized diesel #2. The tests were conducted first by simply changing fuels and testing the vehicle and then by matching the power level on diesel to that on biodiesel. The readings tended to be somewhat erratic with no relationship to earlier transient tests with the exception of NOx, which is depicted, in graphic form below.

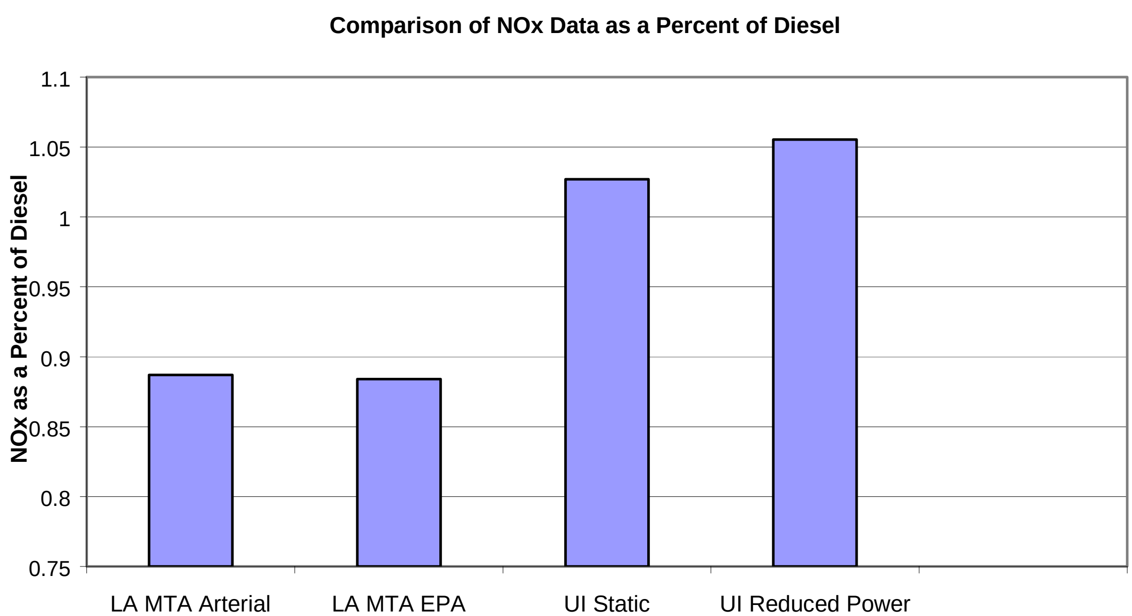

FIGURE 3. LA vs JML NOx Data for REE as a percent of diesel

The overall change in NOx was an increase from biodiesel to diesel of between 2 and 5 percent (Figure 3). The results of the NOx tests from the U of I steady state tests were similar to that normally reported from transient PTO tests where NOx generally increases in contrast to the transient chassis dynamometer tests where NOx has generally been found to decrease. Figure 4, the NOx production for biodiesel and diesel with equivalent power, shows a cross over in these steady state tests. The NOx for biodiesel was below that of diesel at maximum torque and less than that of diesel at reduced torque. Additional tests with NOx comparisons would be justified. Perhaps, the feedstock tests (Peterson et al., 2000) that show reduced NOx with reduced double and triple bonds in the vegetable oil used to produce biodiesel could be replicated to determine if that same relationship could be found in steady state tests on the U of I chassis dynamometer.

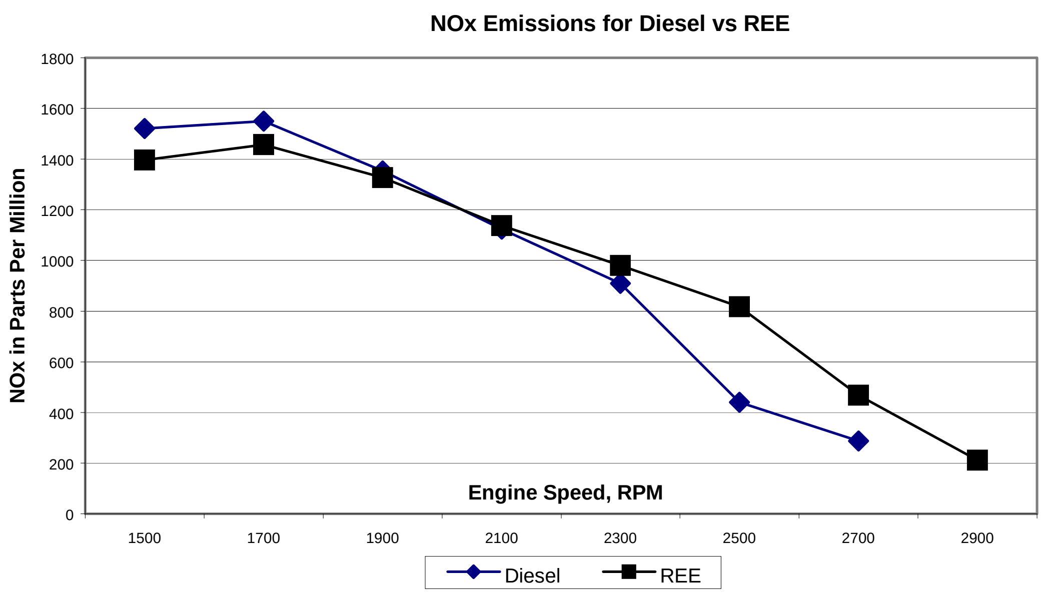

FIGURE 4. JML NOx Emissions for REE and D2

Durability test with a Yanmar, 1.2 L, 3 cylinder, DI Engine

A 200-hour EMA test with MEE, initiated in the spring of 2001, has now been completed. It was interrupted due to the limited supply of Ida Gold fuel at that time. Protocol for this test was developed by BAE and improved upon during subsequent trials (Peterson et al, 1999).

At the start and at each 50 hours the engine was evaluated for torque, horsepower, smoke, injector coking, and oil analysis samples are taken. During the EMA durability tests with the Yanmar engine, MEE power averaged 6.0 percent lower; fuel consumption was 2.2 percent higher and BSFC (hp-hrs/gal) was 8 percent higher than when operated on diesel. The final torque, power curves, and BSFC are shown in Figures 5—7.

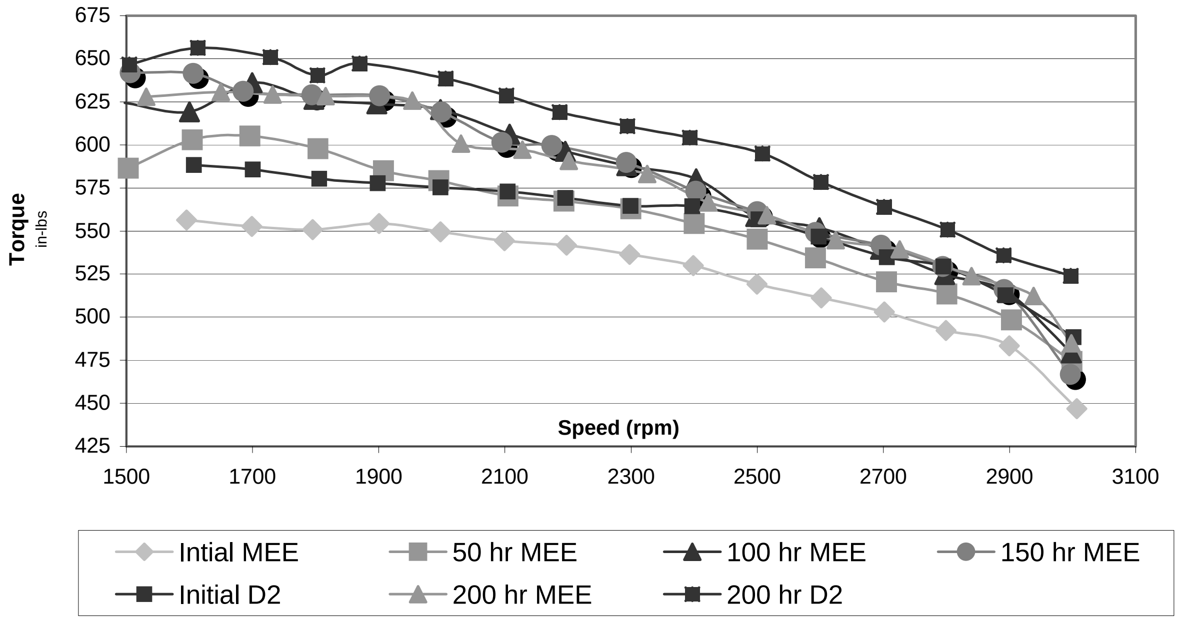

FIGURE 5 Torque curve for 200 hour EMA test

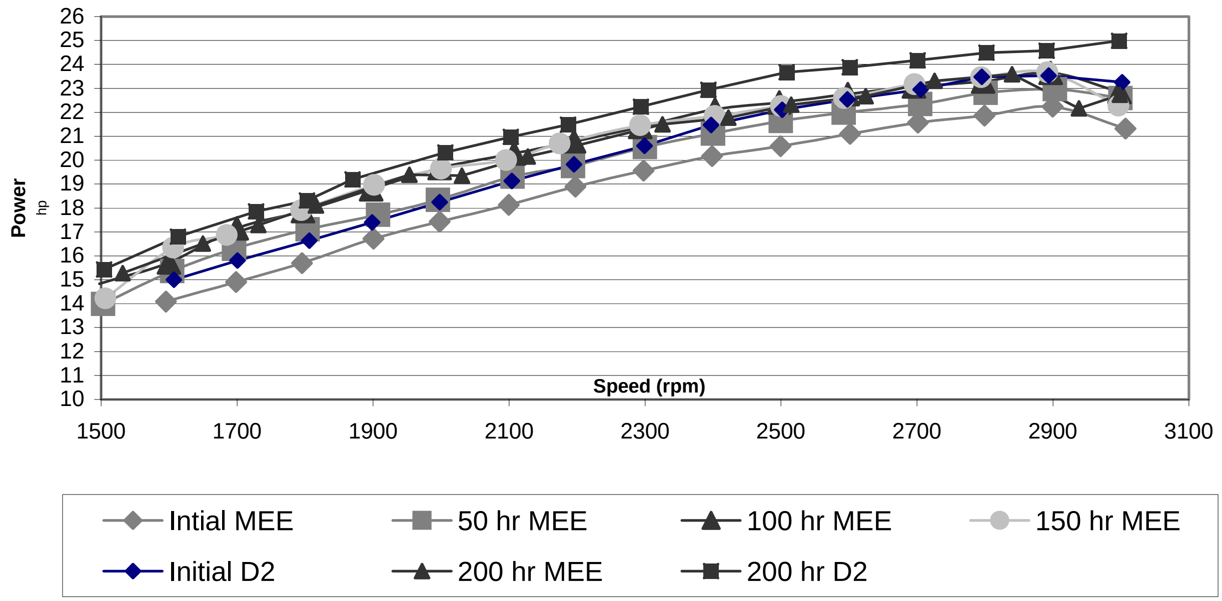

FIGURE 6 Power curve for 200 hour EMA Yanmar test

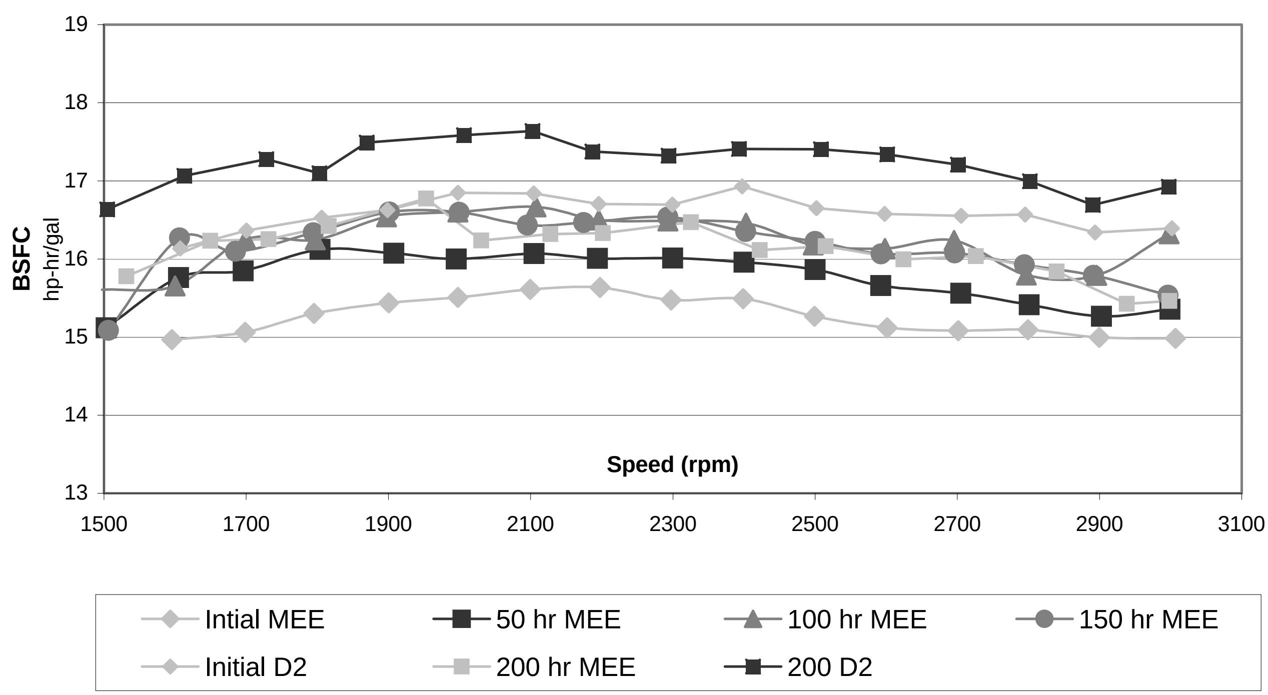

FIGURE 7 Brake specific fuel consumption for 200 hr EMA Yanmar test

Injector Coking Index

The Department has a machine vision system for scoring the results of the injector coking as a way to further evaluate alternative fuels. Figure 8 shows two pictures from the system used for evaluation. On the right is a profile of a clean injector. The number of pixels that make up the tip and shoulders is measured and the area calculated. A coked injector (left) is measured in the same way and compared to the clean one. The difference in area is the amount of coke built up on the injector. Figure 9 shows the results of injector coking at each 50 hours of operation compared to the coking experienced with diesel. A coking index with diesel set at 1 was developed for the comparison (Jones et al, 2001). At each reading the set of three injectors was indexed, evaluated and averaged. The coking on the injectors built up to just over 1.6 times that of diesel and started to decrease possibly due to the self cleaning nature of the fuel and these particular injectors.

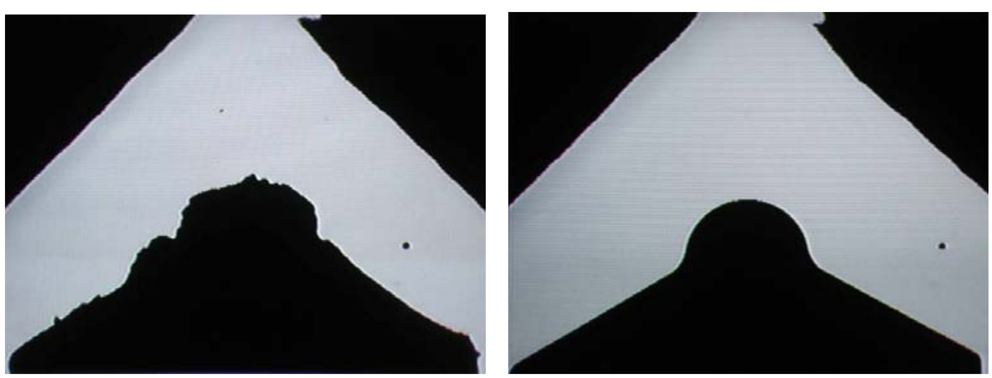

FIGURE 8 Typical coked injector compared to a clean one

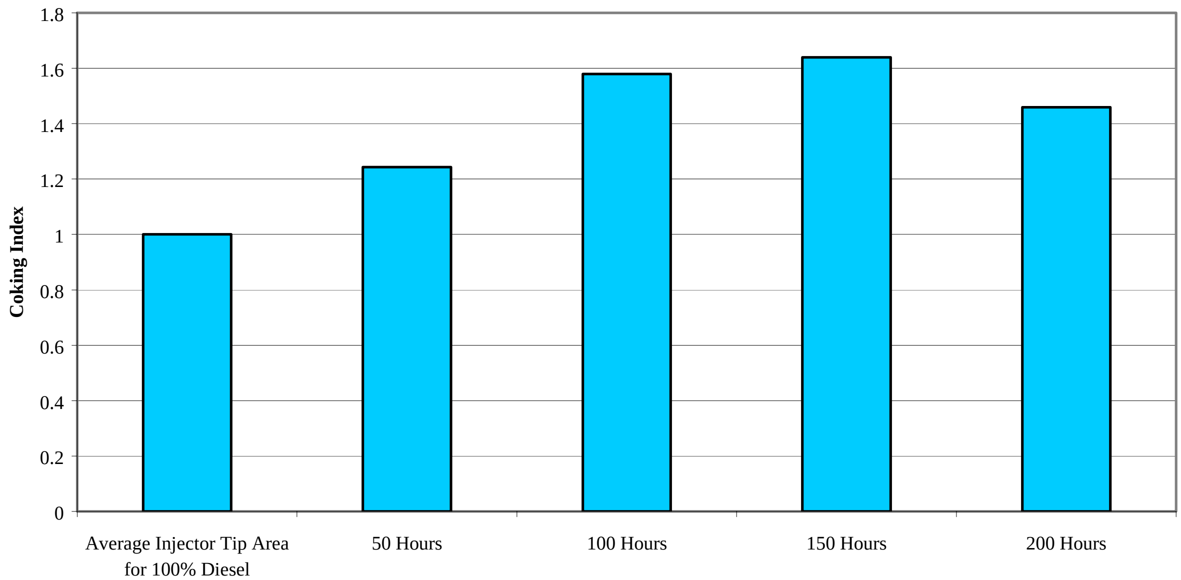

FIGURE 9. Injector coking index for 200 hr EMA test

Oil samples are taken at every 50 hours of operation and sent to a commercial oil analysis lab for evaluation. The results show not only no cause for concern but a very low level of all wear metals. These results are shown in Figure 10. The oil was changed at 100 hours, which accounts for the higher concentration of iron at that point. All of the wear metals decreased at the 150 hour draw and went up slightly again at 200 hours.

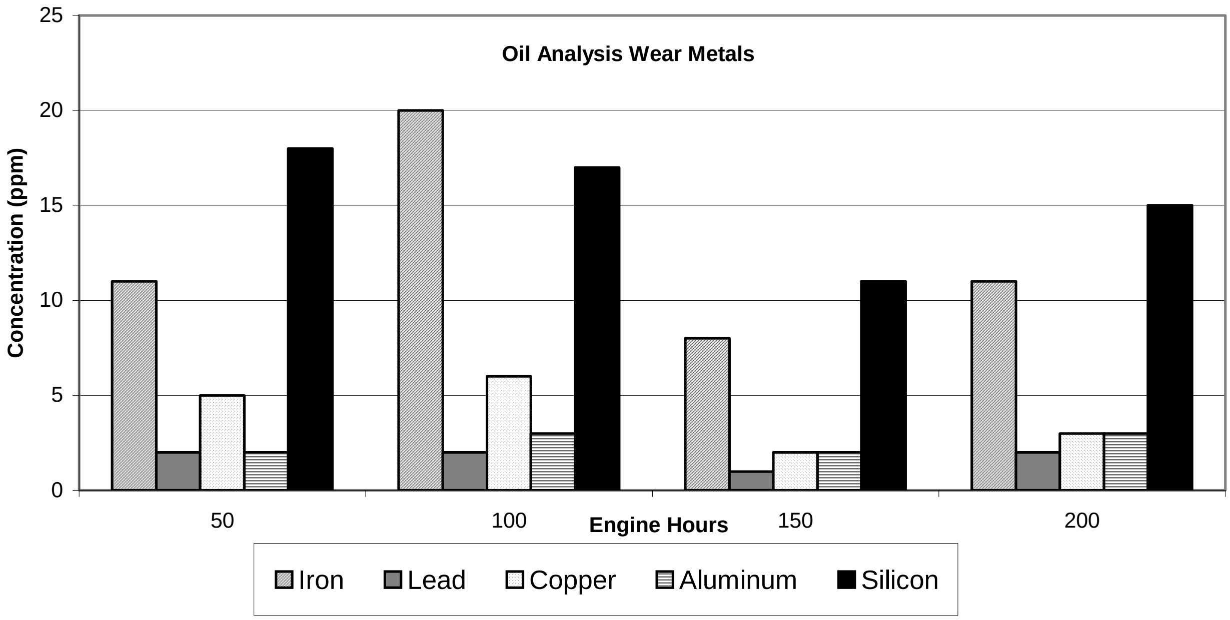

FIGURE 10. Oil analysis wear metals for Yanmar EMA test

Bioenergy 2002

The Tenth Biennial Bioenergy Conference, Bioenergy 2002, "Bioenergy for the Environment," was held in Boise Idaho, at the Center on the Grove, the downtown conference center, from Sept. 22-26, 2002. The conference highlighted the latest in biomass energy technology form around the world. Over 200 presenters, both oral and posters were scheduled with 20 percent of those from non-USA locations. Over 500 registered participants attended.

The conference emphasized using biomass to reduce our dependence on fossil fuels and supplement our regional energy resources while saving the environment. It provided a forum to share and develop new ideas that will improve knowledge of bioenergy as an energy resource. It highlighted successful commercialization efforts and emphasized the biomass renewable resource base that we have all around us. Participants were bioenergy professionals, technology developers, educators, researchers, government officials, entrepreneurs and others who are united in recognizing the advantages of bioenergy renewable resources and the benefits they offer. The University of Idaho and the Idaho Energy Division provided the leadership for the conference. NIATT sponsorship provided funds for travel and other expenses related to development of the conference.

Conclusions

- During the time period of this project, the extraction of 677 gallons of oil from 24,000 pounds of Ida and Pacific Gold varieties of yellow mustard has been completed. Along with the oil, 18,840 pounds of meal were produced for soil fumigation research by the Plant Science Department.
- Oil extraction has been less efficient from yellow mustard than is normally experienced with rapeseed and canola due to the lower oil content of the seed. Ida Gold has only about 24-27 percent oil content and Pacific Gold has about 34-38 percent compared to 40-45 percent for rapeseed. Extraction efficiency, with the small screw presses, for Ida Gold and Pacific Gold was 58 and 70 percent respectively compared to 78-80 percent for rapeseed and canola.
- On-road testing with a 1999 Cummins 5.9B diesel engine in a Dodge pickup truck fueled with yellow mustard biodiesel has accumulated 27,230 miles with no difficulties. Fuel consumption is increased and fuel filter change intervals are decreased over what was experienced with petroleum diesel.
- On-road testing with a 2001 Volkswagen 1.9 L diesel engine has accumulated 12,210 miles. Fuel consumption is about 43 miles per gallon of biodiesel. Drivability of the vehicle is very good. Power and acceleration are excellent. The vehicle is a very “photogenic” ambassador of alternative fuels.
- A 200-hour engine durability test with Ida Gold yellow mustard biodiesel has been completed. Engine oil wear metal analysis data suggests the engine is experiencing a very low level of wear while the injector coking data show an increased amount of carbon on the injector tips compared with diesel.
- The steady state dynamometer provided a very stable platform to produce load settings that could possibly be used for modal emissions tests. A method for controlling the throttle is required for part load tests.
- Bioenergy 2002 was a great success with over 200 presenters and 500 participants. It provided a forum for bioenergy professionals to share and develop new ideas that will improve knowledge of bioenergy as an energy resource.

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